

Electrocardiogram

Recording the electrical activity is known since very long time. The galvanometer is the apparatus designed for that purpose. Any electrical wave has two characters:

Amplitude which is recorded in volt.

Direction which is known by the direction of the wave recorded.

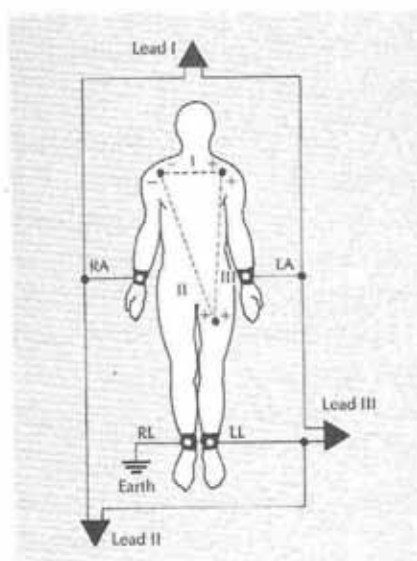
The ECG apparatus is nothing except one which can record an electrical wave regarding its amplitude and direction. The amplitude is known by the number of vertical squares occupied by a certain wave.

The direction of the electrical activity is known by the direction of the recorded wave.

When the electrical activity is in the back of the recording electrode the wave will be negative i.e. downward from the base line and vice versa.

Einthoven supposed that the body is a triangle with the heart as a point in the center.

- He recorded the electrical difference between the right arm and the left arm and termed it as lead I.
- He recorded the electrical difference between the right arm and left foot and termed it lead II.
- He recorded the electrical difference between the left arm and left foot and termed it lead III.

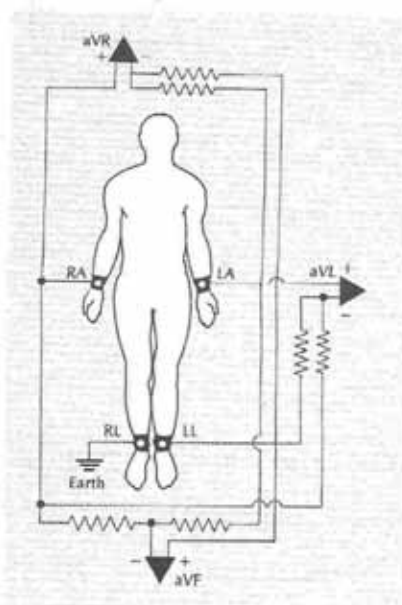


Lead I, II and III are called bipolar limb leads as they record electrical differences only between two limbs.

Wilson observed that the forces obtained from lead I, II and III can cancel out each other when connected to the ECG apparatus by a certain method. He did one electrode which is termed "the central terminal of Wilson". The magnitude of this electrode is zero. Recording the electrical difference between two points using the "central terminal" as one point, the other will read the electrical activity at that point as the other point is zero.

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These are the principles of the unipolar limb leads.

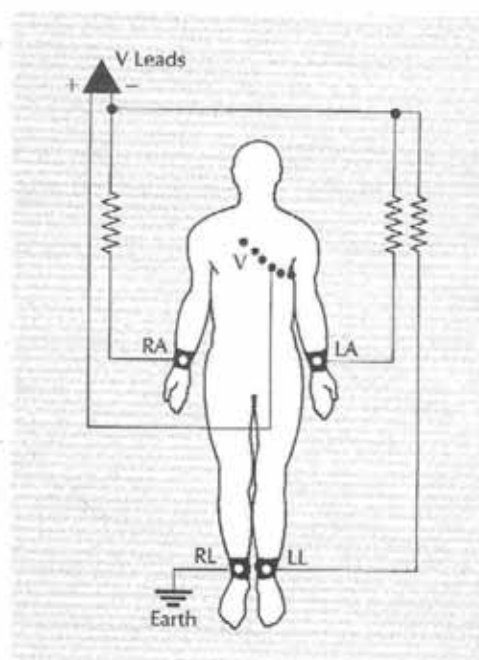
The electrical activity is known at the right arm "volt at right arm VR" and is recorded in the left arm "VL" and is recorded in the left foot "VF" using the zero electrode in the apposite arm.

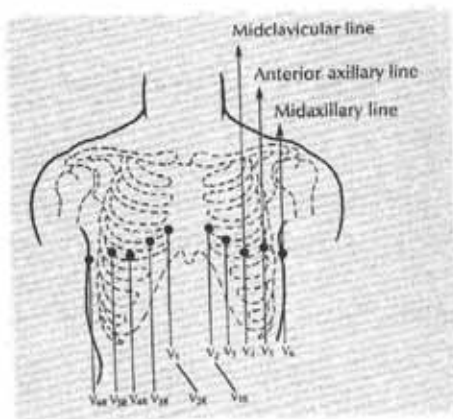
Some technical procedures are done in the apparatus to augment the waves in VR, VL and VF so termed augmented VR, VL, VF or avR, avL and avF.

The exploring electrode may be used on the chest, esophagus or back.

On the chest recording may be standard using six sites.

- V1 Fourth right intercostal space close to the sternum.
- V2 Fourth left intercostal space close to the sternum.
- V3 Between V2 and V4.
- V4 Over the apex.
- V5 On a horizontal line with V4 at the anterior axillary line.
- V6 On the same line but in the mid axillary line.





This exploring electrode or lead may be used to the right "right chest leads".

It may be used through the oesophagus "oesophageal lead"

It may be used below the scapula "Scapular lead".

All are unipolar used in some point using the other electrode zero in force.

The unipolar electrode is a point while the bipolar electrodes are two points.

As mentioned before the ECG apparatus records positive wave or upward deflection when the electrical activity is facing the electrode and record negative wave or downward deflection if the electrical activity is going away from the electrode. This statement is applied on the unipolar leads. The bipolar leads "I, II and III" have two terminals, one is positive and the other is negative.

The negative part of lead I is that on the right and the positive part to the left. The negative part of lead II is its upper part and the positive is its lower part and also LIII, its negative part is the upper and positive is the lower.

The ECG apparatus records positive wave or upward deflection when the excitation wave is going to the positive terminal of the bipolar limb lead and records negative wave or downward deflection when the excitation wave is travelling to its negative terminal.

- Einthoven made three mistakes:

- 1- He considered the heart as a point inside his triangle but in fact the heart is a mass.
- 2- He considered that the body is a homogeneous conductor but in fact electrical activity passing from the heart to the right side will pass in a different structure than when passes to the left side or the foot.
- 3- He considered that his triangle is equal in its limbs but in fact the distance between the right and left arms is different from that from right or left and left foot.

These three mistakes are not of practical importance as they are present in all individuals.

The terminology of the waves:

The electrical activity of both atria is recorded as P wave.

The ventricular complex is recorded as QRS-T complex.

The first negative wave is Q.

The first positive wave is R.

Negative wave following R is S.

When the wave is a big one it is termed by Capital letters Q or R or S and when the wave is a

small one it is termed by small letters q or r or s.

The T wave represents repolarization of ventricular muscles.

The T wave of the atria is not seen as it comes in time with the QRS.

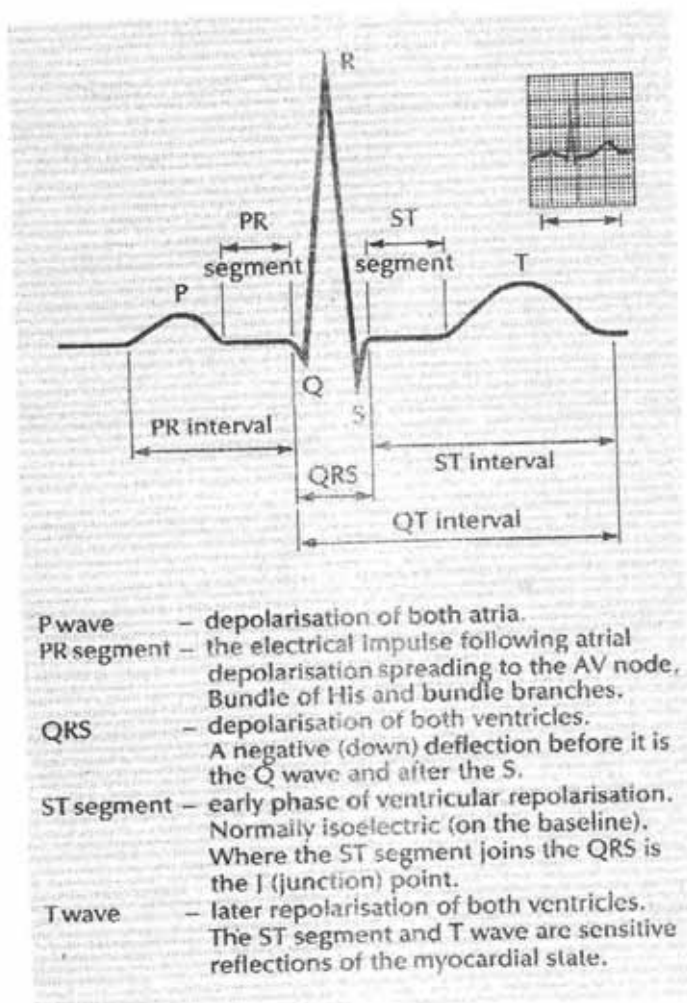
Some records show what is called U wave. It comes immediately after T wave and always in the same direction. Its cause is not known.

The ECG record is interpreted as follows:

1. The rate.
2. The rhythm.
3. The voltage.
4. The rotation.
5. The position.
6. The axis.

After interpreting these six points the individual waves and intervals are looked for:

1. The P wave.
2. The PR interval.
3. The QRS complex.
4. The ST segment.
5. The T wave.
6. The U wave.
7. The QT interval.



1. The rate:

The normal rate is 60-90 beats per minute.

The paper of the ECG apparatus is designed to run at a speed of 25 mm per second, so that the interval between two vertical fine successive lines is 0.04 second.

The rate can easily be determined in a regular heart by dividing 1500 over the interval between the waves needed to determine its rate as $1500 \div RR$ if the ventricular rate has to be determined or $1500 \div PP$ if the atrial rate is the one needed.

1500 small squares represent one minute " $1500 \times 0.04 \text{ sec} = 60$ ".

If the heart is irregular this equation would be inconvenient.

2. The rhythm:

Electrocardiographically the rhythm should be regular and sinus.

The heart is said to be regular when the intervals between the QRS waves are constant and the intervals between P waves are also constant.

The rhythm is said to be sinus when every QRS is preceded by P wave with normal PR interval.

3. The voltage:

If the electrical activity is not prevented from reaching out side, the voltage would be normal, but if any factor or disease causes this electrical activity to be abolished from reaching the

surface of the body, the voltage would be low.

The maximum voltage is obtained when the electrodes are on the surface of the heart. Diminution of the voltage occurs by the presence of the pericardium, the lungs, the chest wall, the subcutaneous tissue and the skin, so low voltage is present in:

- Pericardial effusion.
- Constrictive pericarditis.
- Emphysema.
- Thick chest wall.

The normal voltage is achieved when the sum of R wave in LI, II and III are more than 15 vertical small square.

4. The rotation:

Normally V1 and V2 represent right vent-ricular pattern which is rS while V5 and V6 represent left ventricular patterns which is qR. Between these two patterns the septal pattern which is RS is seen in V3 and/or V4. For detection of the rotation of the heart searching for the leads which show equal R and S in the chest is done. As mentioned it is normally in V3 and/or V4.

Right ventricular hypertrophy makes the heart rotate clockwise – if viewed from below – so the septum goes out. If this occurs the septum would be behind V5 and V6, so the transitional zone in which R equals S would be in V5 and V6 instead of being in V3 and V4.

In cases of left ventricular hypertrophy the heart will rotate anticlockwise – also viewed from below – so the transitional zone appears in V1 and V2 instead of its presence in V3 and V4. This will result in high R wave in V1.

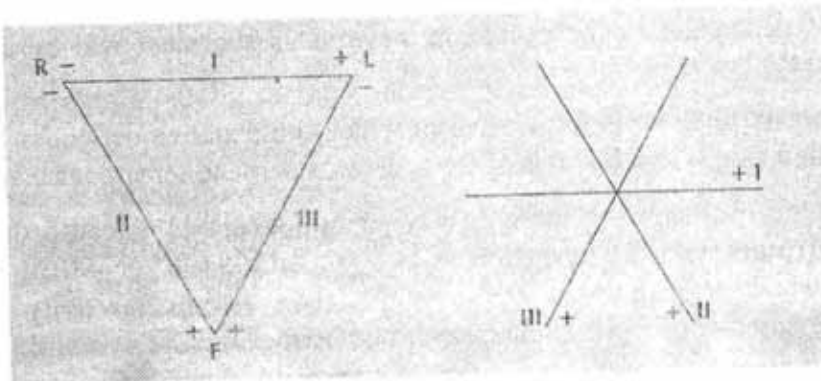
5. The anatomical position of the heart:

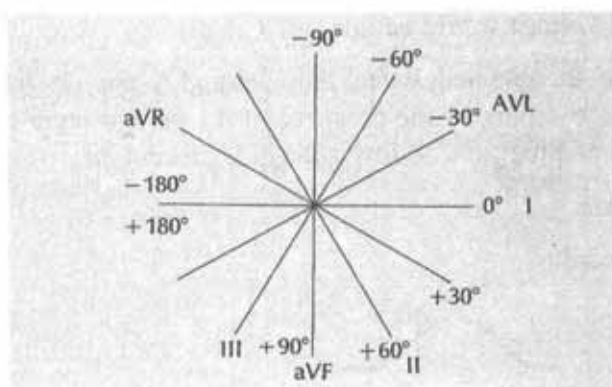
Whether vertical, horizontal or normal can be assessed by the ECG.

The apex of the heart is formed by the left ventricle, so when the heart is vertical, aVF will be the lead in front of the apex and will show left ventricular pattern "qR" and if the heart is horizontal this pattern "qR" will appear in aVL.

6. The electrical axis of the heart:

More than one electrical force are coming out from the heart every cardiac cycle. The electrical axis of the heart is the sum of all these electrical activities. It has a force and a direction. The calculated axis is that of the sum and direction of the forces in the frontal plain only.





There are more than one method to calculate the electrical axis of the heart, some give very accurate results and others are nearly and approximately near accurate.

As mentioned before the recorded wave is positive when the electrode is facing the excitation wave and is negative when the electrode is in the reverse direction.

If the electrode is perpendicular to the electrical activity this electrode will show a wave in which the positive deflection equals the negative deflection.

This is the basis for the calculation of the electrical axis of the heart.

The three bipolar and the three unipolar limb leads will be used for that purpose. A hexaxial system will be formed by these six limb leads. All the six leads will be drawn passing by one point:

Lead I is the horizontal one with the right terminal equals 0° and the left terminal equals 180° .

aVF is the vertical one with the upper terminal equals -90° and the lower terminal equals $+90^\circ$.

Lead II shows its lower terminal at 60° and the upper terminal at -120° .

Lead II shows its lower terminal at $+120^\circ$ and the upper terminal at -60° .

aVR shows its upper terminal at -150° and the lower terminal at $+30^\circ$.

aVL shows upper terminal at -30° and lower terminal at $+150^\circ$.

The word upper and lower is mentioned regarding the horizontal lead which is LI. The terminal above this line is called upper and the terminal below is lower. So it is easy to calculate the axis if it is known which of these six leads was in line with the axis.

As mentioned before the wave will show a negative deflection which equals the positive if the electrode is perpendicular to the excitation wave. This statement will be used to assess the electrical axis of the heart.

Searching in the six limb leads for a wave in which the negative deflection nearly equals the positive deflection means that the axis of the heart was perpendicular over that lead.

For example if the lead showing these near-ly equal deflections is lead I, this means that the axis of the heart runs with the direction of aVF, ie. either $+90^\circ$ or -90° . Inspection of aVF itself can tell whether the axis is $+90^\circ$ or -90° . If the electrical activity is running at the direction of aVF down-wards, the complex will be positive and the axis will be $+90^\circ$, but if the electrical activity is running in the opposite direction upwards aVF will show negative complex and the axis will be -90° . The normal axis lies between -30 and $+90^\circ$.

Axis more negative than -30° is termed left axis deviation. Axis more positive than $+90^\circ$ is

rm right axis deviation.

After interpreting the rate, the rhythm, the voltage, the rotation, the position and the axis, analysis of the waves and segments is carried out. These include:

1. The P wave.
2. The PR interval.
3. The QRS complex.
4. The ST segment.
5. The T wave.
6. The QT interval.

1. The P wave:

Careful inspection of P wave is always done in L II and V1.

The P wave may be:

- Present.
- Invisible.
- Absent.

If present:

It may be normal or abnormal. A normal P wave is upwrite in LI, LII, avF and in the chest leads from V2 to V6 and is inverted in avR.

In LIII, aVL and V1 it may be up write or biphasic.

The maximum duration of the P wave is 0.12 sec. and the maximum amplitude is 2.5 mm.

The P wave may be present but takes an abnormal shape as:

1. *P mitral:*

- Wide "more than 0.12 sec".
- Notched "M shaped".

It is seen in diseases affecting the left atrium as mitral stenosis and mitral insufficiency.

2. *P pulmonale:*

- Tall more than 2.5 mm.
- Peaked.

It is seen in diseases affecting the right atrium as pulmonary hypertension and tricuspid valve disease.

3. *P pulmonale mitral:*

The P wave may be tall more than 2.5 mm and also notched. It is seen in diseases affecting both atria as mitral stenosis with pulmonary hypertension.

The P wave may be present but is inverted in the leads normally showing upwrite P.

- It is inverted in LII, LIII, avF in junctional rhythm.
- It is inverted in LI in cases of dext-rocardia "mirror image".

The P wave may be present but is not seen "invisible":

- In junctional rhythm as the P wave comes in time or just before the QRS complex.
- Sino atrial block.
- Hyperkalaemia as it's amplitude is too small to be seen.

The P wave may be absent in atrial flutter and atrial fibrillation.

Criteria for the ECG diagnosis of atrial flutter:

- Absent P wave.
- The P is replaced by flutter waves wh-ich is regular waves from 250-350 per minute showing saw tooth appearance.
- The best leads showing these flutter waves are LII, III and avF.
- Regular QRS response occurring at a rate equivilant to half or less depen-ding upon the degree of atrio vent-ricular block.

In flutter the response of the ventricle may be irregular and the condition is termed "flutter with variable degree of block" or "fibrilloflutter".

Criteria for the ECG diagnosis of atrial fibrillation:

- Absent P wave.
- The P waves are is replaced by fibrillatory waves which are irregular waves which may be fine or coarse. Recently it was proved that the shape of fibrillary waves has nothing to do either with the aetiology or with the left atrial size.

2) The PR interval:

The normal PR interval is from 0.12 to 0.2 seconds. It is measured from the beginning of the P wave to the beginning of QRS complex.

The PR interval may be:

- Normal.
- Long.
- Short.

I. Long PR may be fixed or changing:

- A fixed prolonged PR is seen in first degree heart block.
- The changing PR in seen either in:
 - Wenchback phenomenon.
 - Complete heart block.

In Wenchback phenomenon the changes in PR interval are fixed to cycles.

II. Short PR is seen in:

- WPW syndrome.
- Junctional rhythm.

3) The QRS complex represents depolarization of ventricular muscle. The Q is the first negative wave, the R is the first positive wave and S is the negative wave following the R wave.

More than one upward deflection is termed R'.

4) The T wave represents the repolarization of ventricular muscle.

Depolarization starts from in to out i.e. from the endocardium to the epicardium and repolarization takes the reverse direction i.e. it starts from out to in i.e. from the epicardium to endocardium.

That is why the QRS and the T wave are always in the same direction. T is normally upwrite in leads I, II and from V3 to V6 while it is inverted in aVR. In leads III, avF, V1 and V2 it may be upwrite, biphasic or inverted.

5) ST segment is measured from the end of QRS complex to the beginning of the T wave. Normally it is isoelectric and slightly curved up. The J point is the junction between the descending limb of the R wave and the ST segment.

6) The "U" wave is a broad low voltage wave that takes the same direction as the T wave Its true cause is unknown.

7) The QT interval represents the time of depolarization and repolarization. It is measured from the beginning of QRS to the end of the T wave.

QT interval changes by change in heart rate, so for a correct measurement it must be corrected to heart rate, so for correct measurement.

$$\text{The corrected QT} = \frac{\text{The measured QT}}{\sqrt{\text{V R} - \text{R}}}$$

This equation is called Bazetts equation.

The QRS complex is demonstrated for:

1. Voltage "hypertrophy".
2. Duration "block".
3. Pattern "infarction".

1) QRS voltage:

The estimation of QRS voltage can help in the diagnosis of left and right ventricular hypertrophy.

1- Right ventricular hypertrophy:

In right ventricular hypertrophy the leads recording the right ventricle show high "R" wave in relation to the "S" wave, so R/S ratio will be more than one. The axis will be more positive than 90 "right axis deviation", P pulmonal usually is associated with electrocardiographic manifestations of right ventricular hypertrophy.

2- Left ventricular hypertrophy:

The forces formed by the left ventricle in V1 and V6 will increase in left ventricular hypertrophy i.e. deep S in V1 and high R in V6. For the correct diagnosis S in V1 + R in V6 or V5 must be more than 35 mm.

This equation can be replaced by the presence of high R "27 mm" in lead V4, V5 or V6.

The diagnosis of left ventricular hyper-trophy can also be established by the sum of the S V2 and R in V5 more than 40 mm or the sum of S in V3 and R in V4 also more than 40 mm.

In left ventricular hypertrophy the S wave in V1, V2 or V3 may exceed 30 mm.

The ST segment may be depressed in V4, V5 and V6 with or without inversion of T wave.

P mitral may associate the above criteria.

II) QRS duration "Bundle branch block":

a- **Right bundle branch block "Rt BBB"** is diagnosed by:

1. Increase in the duration of QRS complex more than 0.12 second.
2. The presence of rSR in V1.

If the second criterion is present but the duration of QRS is from 0.1 to 0.11 second the diagnosis of incomplete right bundle branch block is more convenient.

b- **Left bundle branch block "Lt BBB"** is diagnosed by:

1. Increase in the duration of QRS complex more than 0.12 sec. If from 0.1 to 0.11 second it would be incomplete block.
2. Absent q in V6.
3. Normal pattern of V1.
4. RSR or notched R in V5 and V6.

III) The pattern of QRS:

The normal pattern of QRS complex in the chest leads is very characteristic. It shows small r and deep S in V1 and V2. It shows equal S and R in V3 and/or V4 and shows small q tall R in V5 and V6. Abnormalities of this pattern may be:

- Clockwise rotation:** in which the transitional zone "TZ" in which R equal S moves to V5 and V6 instead of V3 and/or V4. It occurs in right ventricular hypertrophy.
- Anticlockwise rotation:** when the transitional zone "T.Z" moves to V1 and V2 instead of being in V3 and/or V4. Anti-clockwise rotation is one of the causes of high R in V1. Other causes of high R in V1.
 - Below the age of 4 y.
 - In Nigros.
 - Right ventricular hypertrophy "systolic overload pattern".
 - WPW syndrome type A.
 - Strict posterior infarction.
 - Rt BBB.
- Infarction pattern:** transmural infarction or Q infarction is diagnosed by the presence of pathological Q wave "deep and wide" in the chest or limb leads.

Pathological Q in V1 and avR is normal. In V1 the r may be too small to be recorded and avR represents the cavity pattern. In dextroposition of the heart the Q appears in avL instead

of avR.

- Q in V1 and V2 is anterior infarction.
- Q in V3 and V4 is septal infarction.
- Q in V5 and V6 is lateral infarction.
- Q in V1, V2, V3 and V4 is extensive anterior infarction.
- Q in LII, LIII and avF is inferior infarction.
- High R in V1 is seen in strict posterior infarction or what is called true posterior infarction.
- Q in LI and V5 and V6 is seen in antero lateral myocardial infarction.
- Extensive anterior infarction causes the pathological Q to be seen from V1 to V6.

d. **Failure of the R wave to grow** from V1 to V6 is a sign of ischemia.

e. **Non Q infarction:** or non-transmural infarction is diagnosed by the changes in ST segment and T wave changes "vide infra".

The ST segment:

It is the segment between the S wave and T wave.

The J point is the start of the ST segment and lies at the junction of the descending limb of the R wave and the ST segment.

The ST segment may be:

- a. Raised.
- b. Depressed.

ST segment may be normally elevated by 1 mm in avR, avL and avF and by 2 mm in V1 and V2. It may be normally depressed by 0.5 mm in any lead.

Abnormal elevation of the ST segment occurs in:

1. Myocardial injury whether Q or non Q.
2. Pericarditis.
3. Myocardial aneurysm.
4. Early repolarization in normal athletes.

In myocardial infarction three pathological processes occur:

- 1) Ischemia results in symmetrical inversion of the T wave.
- 2) Injury results in the elevation of the ST segment.
- 3) Necrosis results in pathological Q wave.

These three changes may occur either in consequence or simultaneously.

- The raised ST segment in injury pattern is facing only the diseased area while in pericarditis it is usually present in all leads.
- The raised ST segment in injury pattern is convex upwards "convex upwards" while in pericarditis it is curved upwards.
- The raised ST segment in myocardial aneurysm is persistent i.e. it persists for more than six months after the onset of the infarction.

- The raised ST of athletes is usually associated by symmetrical inversion of the T wave. All the changes are corrected by exercise.

The depressed ST segment occurs in:

- Subendocardial injury or ischemia.
- Ventricular hypertrophy.
- Bundle branch block.
- Digitalis effect.

Ischemia causes straight depression of the ST i.e. the J point goes below the isoelectric line.

Digitalis effect causes sagging down of the ST segment i.e. depression with isoelectric J point.

In ventricular hypertrophy the depression is facing the affected ventricle i.e. V1 and V2 in right and V5 and V6 in left and the depression is associated with asymmetrical T wave inversion. ST depression in bundle branch block is associated with increase in the duration of QRS.

The T wave:

Three abnormalities are known:

- Tall peaked T wave occurs in:
 - Hyperkalaemia: The changes occur mainly in the mid pericardial leads.
 - The hyperacute phase of myocardial infarction.
- Inverted T wave.
 - Symmetrical inversion in ischemia.
 - Asymmetrical inversion in hypertrophy.
 - Bundle branch block.
 - Hyperventilation.
- Flat T wave:
 - Myxedema.
 - Pericardial effusion.
 - Constrictive pericarditis.
 - Early in hypokalaemia.

The QT interval:

It is prolonged in:

- Congenital:
 - Jervell – Lange – Nielsen syndrome.
 - Romano ward syndrome.
- Electrolyte abnormalities.
 - Hypokalaemia.
 - Hypomagnesaemia.
 - Hypocalcaemia.

- Drugs:
 - Antiarrhythmic.
 - Tricyclic antidepressant.
 - Phenothiazine.
- Miscelaneous:
 - Bradycardia.
 - Acute myocardial infarction.
 - Some of CNS disorders.

The prolongation of the QT interval may precipitate for malignant ventricular arrhythmia called "torsade de points"

QT interval is short in:

- Hypercalcaemia.
- Digitalis effect.

Some ECG patterns:

1. Myxedema pattern:
 - Low voltage.
 - Sinus bradycardia.
 - ST T wave changes.
2. Emphysema pattern:
 - Low voltage.
 - Clockwise rotation "caused by right ventricular hypertrophy i.e. cor-pulmonale".

Causes of right axis deviation:

- Infancy and childhood.
- Tall slim adults.
- Right ventricular hypertrophy.
- Anterolateral infarction.
- Left posterior hemiblock.
- Chronic lung disease.
- Pulmonary embolism.
- ASD of ostium secundum type.

Causes of left axis deviation:

- Left anterior hemiblock.
- Inferior myocardial infarction.
- WPW syndrome.
- ASD of ostium primum type.
- Hyperkalaemia.
- Tricuspid atresia.